Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE RECIPROCAL RELATION OF SOIL AND INSECTS[1]

J. W. McColloch and Wm. P. Hayes
Kansas Agricultural Experiment Station

The soil is an integral factor in the study of many biological problems. The importance of this has been recognized by the agronomist, the botanist, and the chemist. The zoologist, and particularly the entomologist, on the other hand, have not given the soil the consideration necessary to an understanding of many of the fundamental animal activities. This was brought to the writers' attention in connection with a study of subterranean insects which attack the roots of crops; and the present paper, which might be termed a preliminary survey of the field of soil entomology, is an attempt to review some of the work which has been done along this line and to suggest the scope and possibilities of future research. While the literature on soils and soil insects is voluminous, little effort has been made to systematize or correlate the data. It is only within recent years that the entomologist has recognized the fact that the basis of entomological study is insect behavior, which in turn is a response to the influence of the environmental complex. In other words, we now have the application of the principle of cause and effect, and the entomologist is no longer confined to insects, but investigates all factors which influence their activities.

The soil offers a multiplicity of problems which are of direct interest to the entomologist. It is the home of a vast series of insects either during their entire life or some portion of it. It affords shelter and protection to another large group. In addition, being the medium for plant growth, it becomes a factor in the food supply of insects. Distribution, relative abundance, and seasonal activities of insects may be correlated with certain soil conditions. Finally, a knowledge of soils is fundamental to the development of many control measures. On the other hand, while insect life is largely dependent on the soil, there is also a reciprocal relation, since the soil is benefited by the presence of insects.

THE SOIL AS AN ENVIRONMENT

The soil is a complex of many factors which separately and conjunctively are of vital importance to insect life. Jennings (1906) points out that since the environment is a complex of many factors, every animal lives surrounded by and responds to a complex of factors, at least in its normal life activities within its normal complex. In the case of the soil, the more important factors are topography, texture, structure, color, temperature, moisture, evaporation, light, pressure, food, organic matter, materials of abode, nitrogen, carbon dioxide, oxygen, and enemies. Some of these probably are of little importance in the life economy of soil-inhabiting insects, while others exert a tremendous influence. In many cases it is the interaction of a number of factors that must be considered, and soil technology, therefore, becomes a part of many entomological problems in arriving at an interpretation of the behavior and activities of insects in the soil. Lyon and Fippin (1911), in discussing the principles of soil management, present a comprehensive outline of the factors making up the soil environment.

---

[1] Contribution No. 77 from the Entomological Laboratory, Kansas State Agricultural College. This paper embodies some of the results obtained in the prosecution of project No. 100 of the Kansas Experiment Station.

It is not within the scope of this paper to discuss all of the soil problems involved in a study of subterranean insects, but to indicate something of the complexity of the investigations and the results that may be obtained. With soil temperature, for example, it must be considered that the heat of the soil comes from three sources, solar radiation, conduction, and organic decay; that it influences the biological, physical, and chemical constituents of the soil; and that it is dependent on many factors of the soil, such as specific gravity, specific heat, color, topography, conductivity, air circulation, and water content. Water exists in three forms, gravitational water, capillary water, and hygroscopic moisture, the relative amount of each being determined largely by the physical properties of the soil. The amount of air varies with the different types of soil and in any soil is subject to change from time to time. In general, it may be said that the factors influencing the volume of air are texture, structure, organic matter, and moisture.

The food of subterranean insects consists principally of decaying organic matter and micro- and macro-organisms. All of these occur in varying quantities in practically all soils. Decaying organic matter is probably the most important, since it not only furnishes food for a large number of insects, but also influences the number of micro- and macro-organisms. The amount of organic matter present varies greatly with different soils, a conservative average being from two to three percent. The number of micro-organisms, both plant and animal, in the soil is enormous. In some cases it is estimated that an ounce of fertile soil may contain 30,000,000. A large percent of these belong to the plant group and include bacteria, algae, fungi, and slime molds. The macro-organisms consist of the underground parts of plants and the larger forms of animal life.

The practical application of environmental studies is manifold and should lead to a better understanding of the relation of insects to the soil habitat, the distribution of insects, their relative abundance, their behavior, and finally, in the case of injurious species, to the methods of control. Shelford (1911), writing of the distribution and dispersal of animals, states that every animal selects an environmental complex as its general habitat, that the breeding grounds are usually the most important index to the true habitat, and that each species is usually distributed as far as its environmental complex extends unless barriers are encountered. In support of these statements, Shelford finds that the factors governing egg deposition of certain species of tiger-beetles (Cicindela) are slope, kind of soil, soil moisture, light, and temperature.

The work of Cameron (1913) shows that gravitational water is the most abundant and most destructive form of moisture affecting insect life within the soil, while capillary moisture is the most favorable. In the case of wireworms, Hyslop (1915) states that the larvae of the genus *Melanotus* occur in heavy, poorly drained soils, while Anderson (1920) finds that *Horistonotus uhlerii* infests soils that are classified as fine and very fine sand, whose texture and structure are of such a nature that saturation is almost an impossibility.

INSECTS OF THE SOIL

It might be stated that in a general way all insects are directly or indirectly dependent on the soil, since it is the basis of all life. On the other hand, there is a vast series of insects directly associated with the soil. A review of the orders of insects from the primitive Thysanura to the highly specialized Hymenoptera indicates that practically all of them are represented in the soil fauna. In the present discussion a brief review is given of the orders of insects, indicating the more important groups which utilize the soil. The list, while not exhaustive, is presented to show the great variation in species and their activities.

Thysanura and Collembola.—Especially abundant in the soil, some of the Collembola being found at depths of six feet or more.

Orthoptera.—Examples of the soil-inhabiting insects of this order are the Acrididae, which deposit their eggs in the ground; the Phasmidae, which drop theirs on the surface; and the Locustidae and Gryllidae, many of which spend much of their life underground.

Platyptera.—This order is best represented by the termites.

Ephemerida.—The nymphs of May flies, while they live in aquatic situations, often feed in mud.

Thysanoptera.—Numerous species of thrips are found in and on the ground.

Hemiptera.—The species of this order are found largely on plants. Certain groups, however, as the Cicadidae and the root-feeding species of Aphididae and Coccidae, are intimately associated with the soil. Other families that might be mentioned are the Galgulidae and Saldidae, which live in mud flats, and the Cydnidae, which burrow in sand. Isolated species of Cercopidae, Fulgoridae, and Membracidae are also encountered in the soil.

Neuroptera.—The most striking soil group of this order is the family Myrmeleonidae, the larvae of which construct conical pits in sandy areas for entrapping their prey.

Trichoptera.—These insects, while living in aquatic situations, use sand or soil in some instances for the construction of larval and pupal cases.

Lepidoptera.—This large order contains numerous species that live in the soil for varying periods of their life cycle. In many cases only pupation occurs in the soil, the other stages being above ground. This occurs among certain species of Notodontidae, Geometrina, Sphingidae, and Noctuidae. The larvae of many Crambidae live in nests constructed of bits of earth. Some Noctuidae, especially the cutworms, spend much of the larval period in the ground, and in the case of Chorizagrotis eggs are deposited on clods.

Diptera.—The larvae and pupae of a large number of families of Diptera are found in the soil, and especially that rich in organic matter. Such families as Tipulidae, Tabanidae, Leptidae, Asilidae, Bombyliidae, Therevidae, Dolichopodidae, Mycetophilidae, and Bibionidae are well represented. In the case of Oestridae the larvae are parasitic on mammals, but leave the host to pupate in the ground.

Coleoptera.—The beetles represent one of the largest orders of insects and are especially abundant in and on the ground. Such families as Carabidae, Cicindelidae, Silphidae, and Staphylinidae spend their entire life closely associated with the soil. Nearly all of the Scarabaeidae, Elateridae, Lampyridae, and Meloidae spend the egg, larval, pupal, and part of the adult stage in the ground. Numerous species of other families are well represented in the soil fauna.

Hymenoptera.—The ants, bees, and wasps present many interesting groups of soil-inhabiting insects. The Formicina, Sphecina, and many Apina excavate extensive tunnels, burrows, or cavities in which they store food and rear their young. The adults of many species of Scoliidae burrow through the soil, parasitizing other insects. The mason bees and wasps, while not living in the soil, utilize this material in the construction of their nests. The great variety of species and diversity of habits represented by this order make it one of the most important soil groups.

ABUNDANCE OF INSECTS IN THE SOIL

This phase has not been investigated extensively and offers an exceptionally interesting field for research. McAtee (1907) made a census of the animal life in four square feet of soil to the depth a bird could scratch and on the basis estimated that there were 1,216,880 animals, principally insects, in an acre of woodland and 13,654,710 in meadowland. In addition, he found tangible remains of 488,925 dead insects per acre of woodland and 240,030 per acre of meadowland. Morris (1920), reporting on the fauna of permanent pasture in Cheshire, states that "The census of insects actually found in the samples of soil gave an insect population of 3,586,088 per acre. The family best represented in number of individuals was the Bibionidae, species of which made up 32.4 percent of the total number of soil insects. The next in number were the Mycetophilidae, 16.7 percent, and the Staphylinidae, 12.2 percent. With regard to the number of species occurring in the soil, the Coleoptera, with 29 species, was the best represented order." Marlatt (1907) records 84 periodical cicada openings to the square foot at Frederick, Maryland, and estimates from 30,000 to 40,000 in the ground surrounding a fairly good-sized tree. According to Packard and Thompson (1921), the larvae of the range crane fly often occur in enormous numbers, as many as 300 occurring in an area of one square foot. McCook (1877) records 1,600 nests of *Formica rufa* forming a single colony containing hundreds of millions of workers. There is no doubt that in areas where ants or termites occur the number of individuals present is enormous. It might also be said that soils rich in organic matter usually contain thousands of Thysanura, Collembola, and immature stages of Diptera.

Uses that Insects Make of the Soil

The uses that insects make of the soil and the benefits that they derive are almost as numerous and as varied at the groups of insects themselves. It is not within the province of this paper to enumerate all of these, but rather to call attention to the more striking examples. In general, insects may be said to utilize the soil for shelter, protection, materials of abode, food, moisture, air, heat, and as an avenue of travel. The use of the soil for shelter and protection is often temporary, as in the case of those insects which normally live above ground but burrow into it to escape their enemies, to avoid excessive climatic conditions, or to undergo certain metamorphic processes. On the other hand, many species spend their entire life or the major part of it in the soil. Some of these, as the ants and termites, excavate large subterranean cavities, while others, as the solitary bees and wasps, construct a single burrow or cell. In many instances the soil furnishes shelter and protection for only one or two stages in the life cycle. The Acrididae deposit their eggs in the earth, the other stages occurring above ground, while some Noctuidae are found in the soil in the larval and pupal stages. In connection with the utilization of the soil for protection reference might be made to the peculiar markings of some insects which conform to the general ground color. This is strikingly shown in many of the Acrididae and Cicindelidae, while many species of Rhyncophora, when disturbed, often escape detection by falling to the ground and feigning death. Certain Tenebrionidae have the integument of the elytra coated with so dense a crust of indurate earthy matter that it is impossible to remove it and thus it becomes a part of the insect.

There are many insects that do not live in the soil, but use it in the construction of shelters. The mason bees and wasps build elaborate structures of earth for the rearing of young. Some of the Trichoptera, which live in the water, construct larval and pupal cases of sand, and King (1919) has found that the eggs of some Carabidae are placed in cells made of mud and attached to plants. The enormous termite mounds of the tropics might be placed in this category.

The soil is a vast storehouse of food that is utilized in various ways by insects and many interesting problems arise in connection with a study of the feeding habits of subterranean insects. Many are free-living, moving from place to place in search of food; some are sedentary, while others leave the soil environment, returning with food material. The ants, for example, store seeds, grow fungus, take care of aphids and coccids, are predaceous on other insects, and at times cannibalistic. The larvae of such groups as Carabidae and Asilidae search through the soil for prey. The ant-lion constructs a conical pit for entrapping its food, while the cicindelid larva waits for its prey at the mouth of its burrow. *Canthon laevis* constructs a ball of manure, which is carried to a suitable place and buried, while *Copris carolina* packs its burrow with dung. The Silphidae diligently bury dead animal matter. The solitary wasps fill their excavations with insects and spiders, while the solitary bees fill theirs with pollen. Many parasitic insects invade the soil in search of hosts. The activities of the adults of the various species of Tiphia and Elis, which parasitize white grubs, might be mentioned in this connection. The moles, gophers, and other rodents are infested with lice and in some cases fleas.

The foregoing is not an attempt to cover the field of the food activities of soil-inhabiting insects, but rather to call attention to the variety of habits and suggest the interesting problems of a study of the food habits. Oxygen, moisture, and heat are all essential to the insect's life economy and are supplied in the soil in varying forms and quantities, determined largely by the interaction of many closely related factors. Although these factors are subject to great variation, many insects adjust themselves readily to the fluctuations. Ants move their immature forms from one chamber to another in order to secure optimum conditions, while wireworms, false wireworms, and white grubs burrow laterally or perpendicularly.

Modifications and Adaptions for Living in the Soil

Insects have generally been considered of terrestrial origin, and the greatest modifications have been those which have enabled the species to leave this environment. That development has been from a terrestrial habitat is emphasized by the fact that primitive insects are closely related to this environment. Practically all orders and nearly all families are represented in the soil fauna and the simpler forms of metamorphosis occur in those groups which are largely subterranean. The development of wings, compound eyes, and the more highly specialized forms of metamorphosis have enabled many insects to mitigate the conditions existing outside the soil environment. This phase has been discussed by Osborn (1908), who states that primitive insects were largely terrestrial in habit, and divergence has been along certain main pathways such as adaptation to underground existence, aquatic life, arboreal life, sedentary conditions, parasitic habit, gall-forming habit, and a host of minor lines of special adaptation. He also points out that the tendency to burrow underground is one of the more primitive lines of adaptation. Certain general modifications might be mentioned as associated with subterranean life. Usually the body is more elongate, the sense organs more highly developed, the eyes and wings reduced or wanting, and metamorphosis simple. While all these modifications do not apply to all soil insects, it may be stated that they are often present in direct proportion to the amount of time the insect lives in the soil.

There are a number of interesting modifications which should be mentioned at this time. Several groups of insects exhibit a striking development of the anterior legs for digging and transporting earth. The mole cricket has the front legs modified, resembling those of a mole, and admirably adapted for shoving dirt aside and also for cutting off roots. The anterior legs of the nymphs of the seventeen-year cicada show a peculiar enlargment of the femora and tibia and resemble the cutting mandibles of biting insects. As pointed out by Marlatt (1907), the anterior tarsus of this cicada undergoes a peculiar metamorphosis in the adolescent life, being modified in accordance with the various activities of the insect. Many of the Scarabaeidae also exhibit various modifications of the anterior legs, the tibia being enlarged and flattened, and in some species the tarsi are reduced or wanting.

Certain larvae possess interesting structures which enable them to live in the soil. One of the most striking of these is the larva of the tiger-beetle, which has a hump-like growth on the back of the fifth abdominal segment. This structure bears a pair of long, curved hooks and a pair of short, vertical spines, together with numerous strong bristles. This outgrowth enables the larva to move freely in its burrow and also to maintain its position at the opening.

Benefits to the Soil from Insects

While insects utilize the soil in numerous ways and in many cases are dependent on it for their existence, there is also a reciprocal relation, since insects are an important factor in soil formation, renovation, and maintenance. This fact has been overlooked by many entomologists, although generally recognized by soil students. Van Hise (1904) states that animals perform a very important mechanical function in weathering the rocks, in promoting their transportation, and in exposing new surfaces to the weathering forces; and consequently they greatly accelerate denudation and deposition. Shaler (1891) considers the group of results due to the action of organic life very nearly as important as that brought about by the action of water, and in his discussion of organic life much emphasis is placed on insects.

The importance of insects as beneficial soil agencies may be seen when it is recognized that, with the possible exception of protozoa and nematodes, insects constitute the largest group of the soil fauna. Many species spend their entire life cycle or the greater portion of it below ground, undergoing the vital activities of metamorphosis, growth, feeding, and reproduction in this environment. The larvae of many beetles living in the soil are comparable in their activities to the earthworm which has been discussed by Darwin and others. The methods whereby the soil is benefited by the presence of insect life are too numerous and varied to permit a full discussion at this time. Briefly, these benefits may be considered of a physical and chemical nature and may be classed as interchange of soil, separation of soil, aeration, drainage, and addition of organic matter. Probably the most important activity of insects is that of burrowing through the ground, since this results in the movement of the soil along more or less definite lines and produces an interchange of the subsoil with the upper layer. This phase has not been as fully investigated in the case of insects as it should be. As a parallel, however, Darwin (1883) estimates that earthworms annually bring 18 tons of earth per acre to the surface. Branner (1900), writing of the ants and termites of the tropics, states that the mounds are of great size, numerous, and contain many tons of earth. Shaler (1891) found ants so numerous in a field near Cambridge, Mass., that they transferred enough material each year to cover the surface of the ground with one fifth of an inch of new soil.

In addition to this interchange of soil due to burrowing, the ground is opened up for better aeration and drainage. The data on the extent and distance which insects burrow are very limited. In the case of ants, the galleries and tunnels have been found extending several hundred feet from the nest. In connection with the interchange of soil there is often a separation of the particles. The ants in particular might be mentioned here, since, as pointed out by Shaler (1891), many of them separate the finer detritus from the coarser, placing the finer material on the surface and burying the larger particles.

Another important benefit which the soil derives from insect activities is the addition of organic matter. This is accomplished in numerous ways; one of the most striking and far-reaching is in the case of the interchange of soil. The bringing to the surface of large amounts of earth gradually covers the waste from the aerial parts of plants and incorporates it with the soil. Vegetable matter is also added in large quantities by certain groups of insects which carry plant material beneath the surface. Here, again, the ants are extremely active, although such insects as cutworms and termites might be mentioned. The leaf-cutting ants, which live in large colonies, are capable of stripping a tree of its foliage in a few hours and transporting this material to their nest. Many ants store quantities of seeds in their homes and the solitary bees fill their burrows with pollen.

Another group of insects represented by the various members of the Scarabaeidae incorporate considerable organic matter with the soil by digging burrows in which they bury manure as food for the larvae. Shaler (1891) states that a single pair of beetles will add several cubic inches to the soil in a year.

While many insects add vegetable matter to the soil, some are active in burying animal matter. The Silphidae should be mentioned especially in this connection, since they bury dead animals by removing the earth, allowing the body to settle until finally it is below the surface. Shaler (1891) states that were it not for such insects the surface of the earth would be covered with a deep layer of bones. Many of the solitary wasps kill or paralyze insects and spiders, which they then place in burrows in the soil.

Several other benefits to the soil might be mentioned. Many insects in feeding underground ingest considerable soil matter and this is acted upon by various body secretions which decompose the inorganic matter and cause certain chemical changes. This material also often undergoes a grinding process in the proventriculus which reduces the soil particles and renders them more susceptible to the active body compounds. This phase has not been investigated in insects, but several workers have conducted experiments along this line with earthworms. The excreta of insects which soon becomes incorporated with the earth is composed largely of active chemical compounds which add much to the soil. Juritz (1920) made an analysis of the droppings of *Antheraea cytherea* and compared it with horse, cow, and barnyard manures. The caterpillar droppings contained a relatively high percentage of potash, and compared favorably with the other manures in their contents of nitrogen, lime, and phosphoric acid. The decomposition of dead insects either above or below ground might also be mentioned, since much is added to the soil in this process. And finally, organic matter already occurring in the soil is rapidly decomposed and made available as plant food by the work of various insects.

THE RELATION BETWEEN SOIL TECHNOLOGY AND INSECT CONTROL

Economic entomologists, and particularly those engaged in the study of cereal crop insects, are directly interested in soil problems in connection with the development of control measures. Many of the methods advocated for the control of insect pests are dependent on general agricultural activities, which in themselves are closely related to soil conditions. In general, it might be stated that a knowledge of the soil is fundamental in any control measure involving cropping, cultivation, use of soil fumigants, sprays, and repellents.

Cropping

The rotation of crops is one of the more generally recommended control measures for many insects. It is especially valuable for such pests as are limited to one food plant or group of closely related plants, or in the case of such species as are slow in dispersal. Rotation, however, can not be practiced successfully unless the soil conditions are definitely known. As Lyon and Fippin (1911) point out, it is a matter of common observation that all crops do not grow equally well upon the same soil. Each plant is adapted to make its best growth on a particular soil and under a particular climate. Any departure from these ideal conditions results in changing the character of the plant and in reducing its value.

Cultivation and Handling of the Soil

The entomologist is often confronted with the problem of developing some cultural system for the control of insect pests. This system may involve such practices as plowing at different seasons of the year, listing, disking, harrowing, cultivation, and summer fallowing. In order to know just how far these operations can be carried out, it is necessary to have a thorough knowledge of the soil, otherwise more harm may be done than good. Soils respond differently under cultivation, and the successful manipulation of the ground is dependent on a knowledge of the important factors involved. Tillage produces a modification of the food, temperature, moisture, air, and texture of the soil. Good cultural management, therefore, involves an analysis of the existing condition of the soil and a determination of the changes to be effected.

The Use of Soil Fumigants

Soil fumigation has recently come into prominence as a method for the destruction of several insects and particularly the grubs of the Japanese beetle. A résumé of the literature indicates that this field of investigation is just beginning. The experimental work will of necessity follow many lines, and soil technology will have an important place. Komp (1920), in outlining the problems connected with a study of soil fumigation with carbon bisulphide, says that it is necessary to determine the maximum dosage non-injurious to the plant, the minimum dosage lethal to the insect, and the influence of temperature and moisture conditions upon the effectiveness of the fumigation. De Ong (1917), writing of sodium cyanide, states that (1) a definite ratio must be established between the minimum point of toxicity to the insects and the maximum dosage which is safe for germinating seeds and plants, and (2) a study must be made of the physical and chemical action of the gas in the soil, the rate and extent of diffusion and absorption by soil water, the absorption of the gas by soil particles, and its decomposition by certain soil constituents. In addition, the effect of soil fumigants on micro-organisms such as protozoa and nitrifying bacteria must be determined.

Use of Sprays

The use of insecticides against subterranean insects has never been developed and presents many problems for investigation similar to those mentioned for soil fumigation. Alwood (1888) experimented with kerosene emulsion against the grubs of *Cotinis nitida* with some degree of success. Cotton (1918) and Davis (1920) tried insecticides on white grubs with no promising results.

Another phase of soil study in relation to the use of sprays is suggested by the papers of Headden (1908) and Ball (1909) on the arsenical poisoning of fruit trees. In the spraying of trees or other plants with arsenical or contact sprays, varying amounts of the material fall to the ground at the time, while practically all of it ultimately reaches the soil. In the case of orchards, where a number of applications are made annually, the amount of poison reaching the ground becomes large, and this raises the question of the effect of spray materials on the soil. Headden, after investigating a diseased condition of fruit trees in Colorado, attributed much of the trouble to arsenical poisoning. Ball, while not agreeing with many of Headden's conclusions, states that the entire subject of arsenical poisoning is a matter for careful and exhaustive investigation.

Use of Repellents

The use of repellents for the prevention of injury to seeds between the time of planting and germination by such insects as ants, wireworms, false wireworms, and seed maggots is one of the older remedies advocated. The list of repelling agents recommended at various times is extensive, and it is necessary to mention only some of the more common ones, such as kerosene and other petroleum oils, crude carbolic acid, creosote, coal tar, turpentine, and oil of tansy. Three distinct methods of application are recognized: dipping or soaking the seed in a repelling agent; mixing the repellent with some fertilizer—for example, bone meal—and sowing with the seed; and the application of the repellent to the surface of the ground. The first method is generally advocated in the case of injury to germinating seed, the second has received attention in connection with the corn-root aphis, and the third has been recommended against the seed-corn maggot.

While the use of repellents has long been advocated, the conflicting results which have been obtained indicate that there is opportunity here for investigational work. A summary of the experimental work indicates that no satisfactory substance has been found which can be depended upon under the varying conditions existing in the soil. The problems connected with the use of repellents must be along two general lines: (1) the development of a repellent that is objectionable to the insect and at the same time not injurious to the seed, and (2) the influence of soil conditions on the effect of the repellent against the insect and on the germination of the seed.

Miscellaneous Control Measures

Various control measures are advocated from time to time which involve a knowledge of soil conditions and the effect which these measures will have on the ground. The use of such fertilizers as lime, kainit, and nitrate of soda is often recommended either as an insecticide or for the purpose of stimulating growth, thus enabling the plant to overcome insect injury. Under this category might be mentioned the dynamiting of the soil suggested by Cotton (1918) to destroy white grubs, the use of tile drains as recommended by Hyslop (1915) for the control of certain species of wireworms, and irrigation advocated by Parker (1915) against the sugar-beet root-louse.

Summary and Conclusions

In conclusion, the writers desire to emphasize that this paper is a preliminary presentation of the relations of insects and soil, a complete discussion of which would fill a large volume. No attempt has been made to cover the entire field nor to make an exhaustive review of the literature. It has been the purpose rather to emphasize the importance of the soil as an environment. Much has been written on the biology of aquatic situations and plant associations, but the thin layer of soil which supports all plant and animal life is still open for extensive investigation. The problems are unlimited and are of the greatest fundamental importance to the progress of agriculture. To the entomologist the field is especially attractive. The soil is a complex of many factors which separately or conjunctively are of vital importance to insect life. Insects constitute one of the largest groups of the soil fauna, and practically all orders are represented. The principal uses which insects make of the soil are for shelter, protection, material of abode, food, moisture, air, heat, and as an avenue of travel. Insects exhibit many striking modifications and adaptations for living in the soil environment. The reciprocal benefits to the soil through insect activities are numerous and varied and may be classed as soil formation, renovation, and maintenance. The influence of the great number of interacting factors of the soil environment tax the resources of the investigators in this field. And finally the economic entomologist finds that a study of the soil is fundamental to the development of many control measures.

LITERATURE CITED

Alwood, W. B.
'88 Kerosene Emulsion as a Remedy for White Grubs. Insect Life, 1: 48–50.
Anderson, G. M.
'20 The Slender Wireworm: Its Relation to Soils. So. Carolina Agri. Exp. Sta., Bull. 204, pp. 1–14.
Ball, E. D.
'09 Is Arsenical Spraying Killing Our Fruit Trees? Journ. Econ. Ent., 2: 142–148.
Branner, J. C.

'00 Ants as Geological Agents in the Tropics. Journ. Geol., **8**: p. 152.

Cameron, A. E.
'13 General Survey of the Insect Fauna of the Soil within a Limited Area near Manchester (England): A Consideration of the Relationships between Soil Insects and the Physical Conditions of their Habitat. Journ. Econ. Biol., **8**: 159–204.

Cotton, R. T.
'18 Experimental Work on the Control of the White Grubs of Porto Rico. Journ. Dept. Agr., Porto Rico, **2**: 1–18.

Darwin, C.
'83 The Formation of Vegetable Mould. P. Appleton & Co., New York, 313 pp.

Davis, J. J.
'20 Miscellaneous Soil Insecticide Tests. Soil Science, **10**: 61–75.

DeOng, E. R.
'17 Hydrocyanic Acid Gas as a Soil Fumigant. Journ. Agr. Res., **11**: 421–436.

Headden, W. P.
'08 Arsenical Poisoning of Fruit Trees. Colo. Agr. Exp. Sta., Bull. 131, pp. 1–27.

Hyslop, J. A.
'15 Wireworms Attacking Cereal and Forage Crops. U. S. Dept. Agri. Bull., 156, pp. 1–34.

Jennings, H. S.
'06 Behavior of the Lower Organisms. Columbia Univ. Press., New York, pp. 366.

Juritz, C. F.
'20 Analysis of Droppings of Caterpillar (*Antheraea cytherea*). Chem. News, **121**: 181.

King, J. L.
'19 Notes on the Biology of the Carabid Genera *Brachynus, Galerita,* and *Chlaenius*. Ann. Ent. Soc. Amer., **12**: 382–388.

Komp, W. H. W.
'20 The Use of Carbon Bisulphide against the White Grub. Soil Science, **10**: 15–28.

Lyon, T. L., and Fippen, E. O.
'11 The Principles of Soil Management. Macmillan Co., New York, pp. 531 + xxxiii.

Marlatt, C. L.
'07 The Periodical Cicada. U. S. Dept. Agri., Bu. Ent., Bull. 71, pp. 1–181.

McAtee, W. L.
'07 Census of Four Square Feet. Science, N. S., **26**: 447–449.

McCook, H. C.
'77 Mound-making Ants of the Alleghenies, their Architecture and Habits. Trans. Amer. Ent. Soc., **6**: 253–296.

Morris, H. M.
'20 Observations on the Insect Fauna of Permanent Pasture in Cheshire. Ann. Appl. Biol., **7**: 141–155.

Osborn, H.
'08 The Habits of Insects as a Factor in Classification. Ann. Amer. Ent. Soc., **1**: 70–84.

Packard, C. M., and Thompson, B. G.
'21 The Range Crane-flies in California. U. S. Dept. Agr., Dept. Circ. 172, 8 pp.

Parker, J. R.
'15 Influence of Soil-moisture upon the Rate of Increase in Sugar-beet Root-louse Colonies. Journ. Agr. Res., **4**: 241–250.

Shaler, N. S.
'91 The Origin and Nature of Soils. Twelfth Ann. Rept., U. S. Geol. Surv., Pt. I, pp. 213–345.
Shelford, V. E.
'11 Physiological Animal Geography. Journ. Morph., **22**: 551–618.
Van Hise, C. R.
'04 A Treatise on Metamorphism. U. S. Geol. Surv. Monogr., **47**, 1286 pp.